DATA (Note 2)									
Hazardous Material		1	1.00	0.004	0.0000011	1	1.00	0.004	0.0000011
S Control and General	Public Safety Reports	1	5.00	0.004	0.0000056	1	5.00	0.004	0.0000056
	Missing	1	0.80	0.050	0.0000111	1	2.40	0.050	0.0000333
	Unidentified	1	0.80	0.200	0.0000444	2	2.40	0.200	0.0002667
Stolen Articles	License Plate	1	0.80	0.100	0.0000222	2	2.40	0.100	0.0001333
	Serial Number	1	0.80	0.027	0.0000060	2	2.40	0.027	0.0000360
	Identification Number	1	0.80	0.067	0.0000149	1	2.40	0.067	0.0000447
Alarm Compliance	Burglary	1	0.80	0.027	0.0000060	1	2.40	0.027	0.0000180
	Ringing	1	0.80	0.013	0.0000029	1	2.40	0.013	0.0000087
	Vandalism	1	0.80	0.050	0.0000111	1	2.40	0.050	0.0000333
	Robbery	1	0.80	0.050	0.0000111	1	2.40	0.050	0.0000333
For Information (FI)	Suspicious Persons	1	2.40	0.333	0.0002220	1	4.00	0.333	0.0003700
Addr/Tel Info (ATI)	Suspicious Persons	1	1.60	0.286	0.0001271	1	4.00	0.286	0.0003178
Voiceless Dispatch	(see voice)								
Total Contributions		13	17.20	1.211	0.0004856	16	35.60	1.211	0.0013018

STATUS	Special Info/Enroutes	1	0.03	3.000	0.0000250	1	0.03	1.500	0.0000125
SYSTEM CONTROL									
Security	Registration								
	Authentication	1	1.03	0.009	0.0000027	1	1.03	0.009	0.0000027
	Corroboration	1	3.09	0.009	0.0000080	1	3.09	0.009	0.0000080
Total Contributions		3	4.15	3.019	0.0000357	3	4.15	1.519	0.0000232

Advanced Digital Wireless Technologies
- Issues and Commentary -

Dr. Gregory M. Stone

March 1, 1996

Wireless Digital Communications Fundamentals

The Bandwidth Controversy

Bandwidth and information transfer capacity are NOT synonymous.

- Bandwidth: The range of frequencies within which performance, with respect to some other characteristic, falls within specific limits. Bandwidth is expressed in terms of Hz.
- Information transfer capacity: The rate of information transfer at maximum channel capacity. Information transfer capacity is expressed in b/s.
- Emerging multimedia digital services do NOT require additional bandwidth *per se*
- Information rich multimedia digital services require greater channel capacities

Symbol Transmission Rate Theoretical Limit

Nyquist Minimum Bandwidth

- For a signaling at a symbol rate of 1/T, in a zero intersymbol interference (ISI) environment is (1/2T) Hz or two symbols per second per Hertz, assuming the Nyquist rectangular Type I pulse

  2 S/s/Hz

- Thus, for a 3.1 kHz Nyquist Bandwidth, the maximum ISI free symbol rate is 6.2 Kilo Symbols per Second (6.2 KS/s)

Adapted from: Feher, Kamilio, "Advanced Digital Communications," Prentice-Hall, Englewood Cliffs, NJ, 1987.

Channel Capacity Theoretical Limit

Shannon-Hartley Channel Capacity Theorem

- The maximum transmission rate (C) at which information may be transported over a channel characterized by additive white Gaussian noise, without error is:

$$C = B \log_2 (1 + E_b/N_o) \text{ [bits/sec]}$$

Where:

C is channel capacity in bits per second (b/s)

B is given bandwidth in Hertz (Hz)

E_b/N_o is signal energy per bit to noise ratio, typically expressed as detection system input carrier-to-noise ratio (CNR)

- For a given bandwidth (B) channel capacity is quasi-linearly related to E_b/N_o. Bandwidth efficiency (C/B) is expressed in terms of bits-per-second-per Hertz or b/s/Hz

$$C/B = \log_2 (1 + E_b/N_o) \text{ [bits/sec/Hz]}$$

Channel Capacity Theoretical Limit (Continued)

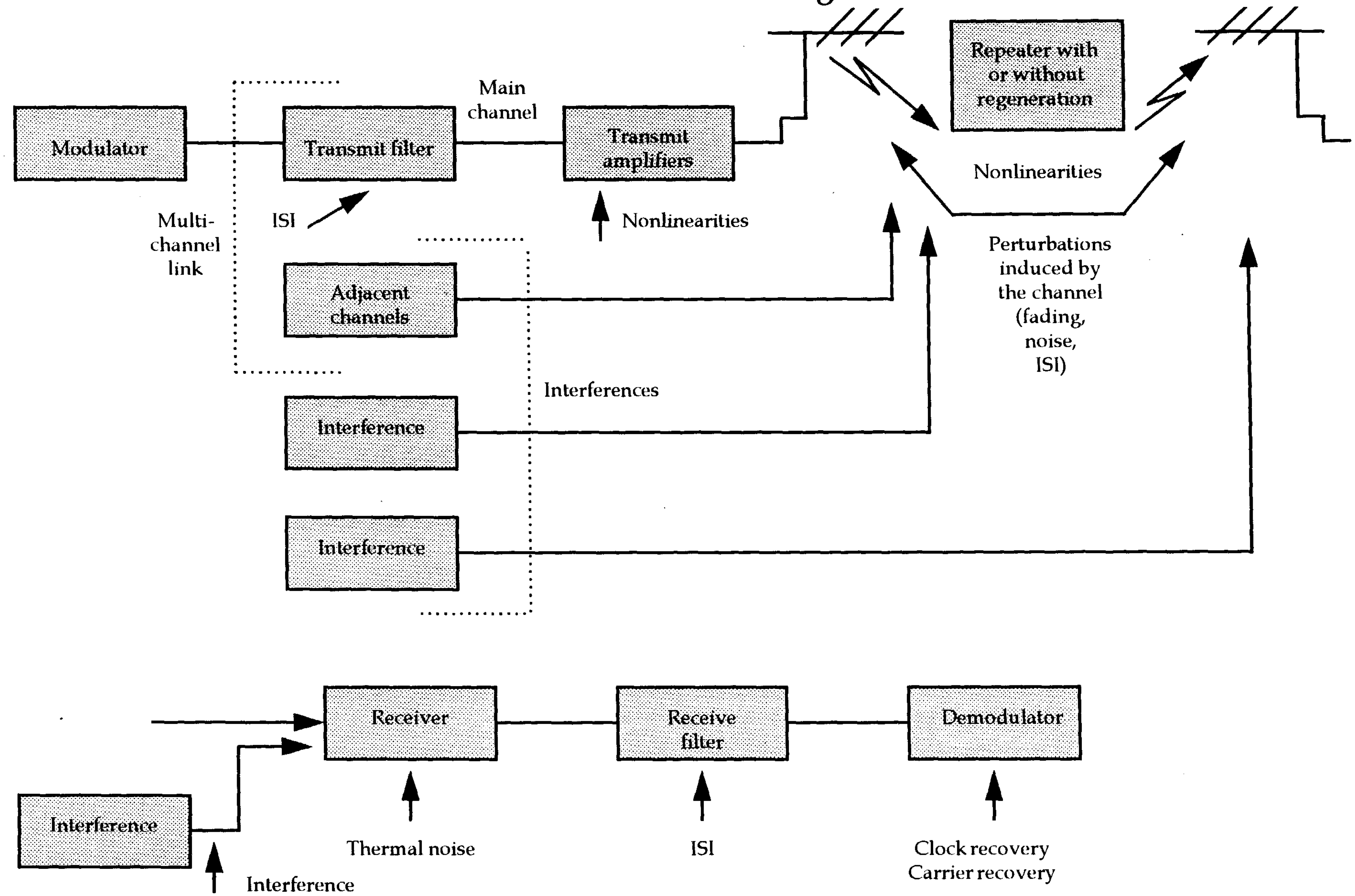
C/N in dB	Bandwidth Efficiency in b/s/Hz
0	1
4.8	2
8.5	3
11.8	4
14.9	5
18	6
21	7

Adapted from: Webb, W.T. and Hanzo, L., "Modern Quadrature Amplitude Modulation," Pentech Press, London, United Kingdom, 1994.

The Information Transmission Challenge: Overcoming Channel Impairments

- Ideal Channel
  - Impulse response is a linear transfer function, thus it Linear Time Invariant
  - Only perturbation is Additive White Gaussian Noise (AWGN)
  - Distortion free with Flat Frequency Response and Linear Phase
- Benign Channel
  - Perturbed by
    - » Some linear distortion, i.e., non-flat frequency response
    - » AWGN in detection system

Distortions and Perturbations Affecting a Transmission Link



The Information Transmission Challenge: Overcoming Channel Impairments (Continued)

- Mobile Radio Channel
  - Randomly time variant linear channel
  - Perturbed by
    - » Lognormal variations in signal amplitude due to terrain shadowing
    - » Rayleigh variation in signal amplitude and phase due to multipath
    - » Doppler shift in frequency due to vehicle motion
    - » Time dispersion (delay spread) or time variance of the channel's impulse response due to multipath and frequency selective fading
    - » AWGN
      - Co-Channel Interference
      - Adjacent Channel Interference

The Information Transmission Challenge: Overcoming Channel Impairments (Continued)

- Solution

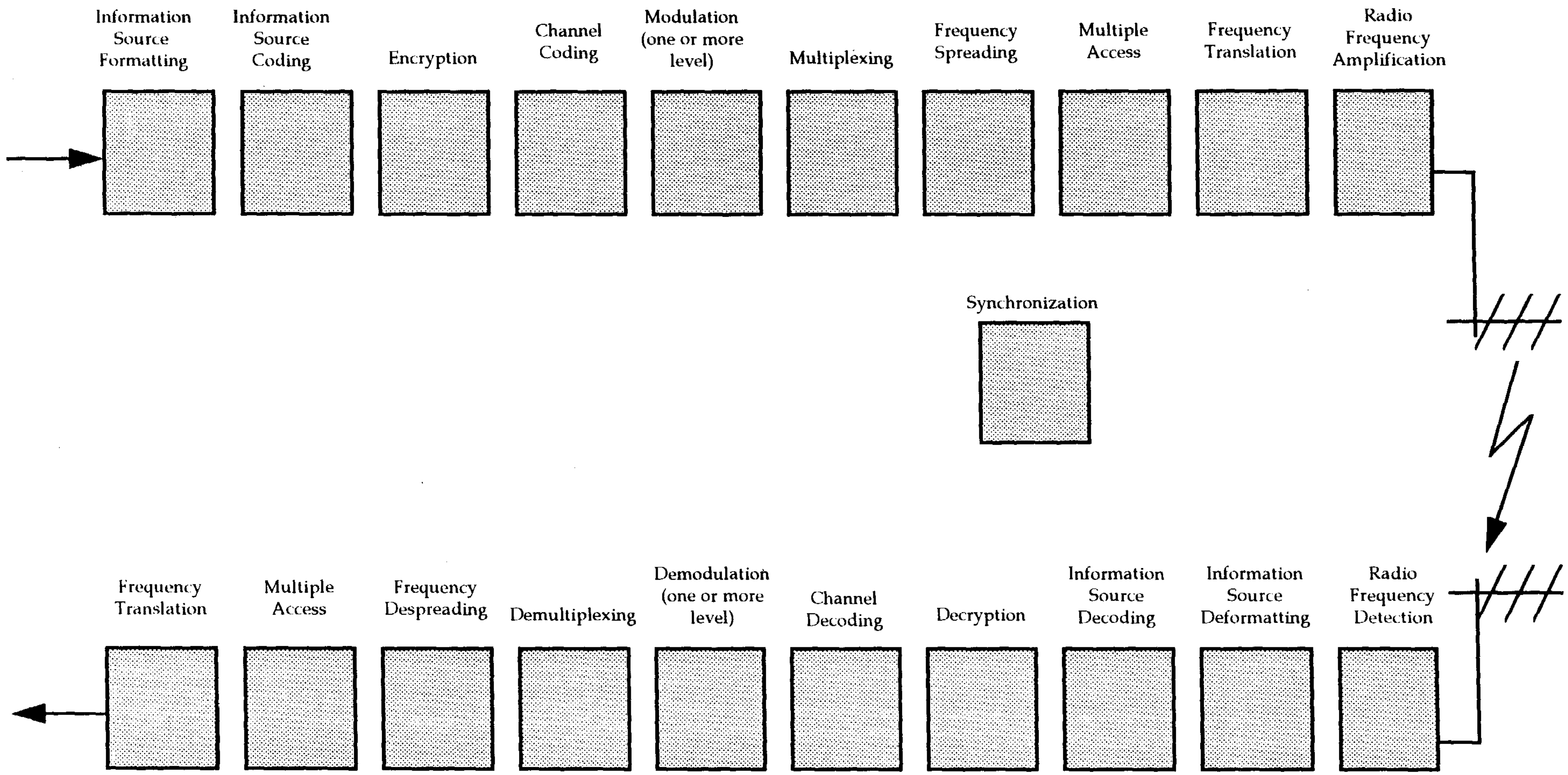
  Use various techniques to deperturb a time variant non-linear mobile channel to create quasi-ideal linear phase time invariant channel

Fundamentals Appertaining to the Conveyance of Digital Information by Wireless Means

- In bandpass (passband) systems (i.e., wireless) DIGITAL information is transformed by modulation process so that the Radio Frequency Sinusoidal Carrier is modulated by the digital information sequence in either the amplitude, phase, frequency domains, or some combination of amplitude and phase
- Thus, RF transmission is inherently a continuous ANALOG process
- Parametric performance of ANY wireless information transport system is DEPENDENT upon how each of these transformations is implemented
- Multiple transformations employed to effect information transport from Source to Destination

Fundamentals Appertaining to the Conveyance of Digital Information by Wireless Means (Continued)

- Transformation Functional Classes include:
  - Information Source Formatting/Deformatting
  - Information Source Coding/Decoding
  - Encryption/Decryption
  - Channel Coding/Decoding
  - Modulation (one or more level)/Demodulation
  - Multiplexing/Demultiplexing
  - Frequency Spreading/Despreading
  - Multiple Access
  - Frequency Translation/Detranslation
  - Radio Frequency Amplification



Adapted from: Sklar, B., "A Structured Overview of Digital Communications - A Tutorial Review - Part 1," IEEE Communications Magazine, August 1983.

Projected Technology Evolution

Source Coding and Compression

- Vector quantized linear predictive coding
  - Toll quality digital voice at 1,000 to 2,400 b/s
- Compression via Wavelet Transformation for multimedia data
  - 100-1 improvement projected in real-time interactive video, i.e., 10 MB/s to 100 kb/s

Channel Coding, EDAC, Modulation, and Frequency Translation

- m-ary Trellis coded up to 1024 levels
- Soft Decision Viterbi Decoding
- Multi-carrier/multi-tone linear modulation
- Linear frequency translation/conversion

Radio Frequency Power Amplification

- DSP and MMIC advances will result in major gains in efficiency and cost
- Very broad band (100-2500 MHz) and high power (10 kW+ PEP) linear amplifiers
- Near loss less low power combining of multiple sources into a multifrequency adaptive linear antenna array minimizing infrastructure costs

Advanced Linearization and Detection Techniques

- Transform Hostile Mobile Channel into a Time Invariant, Phase Linear AWGN Channel via Channel Linearization and Deperturbation
  - Transparent Tone-In-Band (TTB)
  - Feed Forward Signal Regeneration (FFSR)
  - Pilot Symbol Assisted Modulation (PSAM)
  - Ratio squared combining at RF, IF, and Baseband

Advanced Linearization and Detection Techniques (Continued)

- Detection Systems
  - Direct conversion linear detection systems with very high dynamic range (in excess of 150 dB)
  - Very low noise radio frequency front ends with noise figures of .1 dB with bandwidths of 100-200 MHz
  - Advancements in analog-to-digital (A/D) converter resolution, speed, and in minimizing stray capacitance and propagation delays in the ASIC

Synchronization

- Continuous network frequency and phase synchronization
- Economically viable frequency control and stability obviating the need for "guard band" allocations

Digital Signal Process & Signal-to-Noise Ratio Improvements

- Specialized digital signal processor (DSP) employing .05 to .1 uM technology
- Very low power DSP's at a performance level in excess of 5,000 MIPS
- C/N improvements through DSP based adaptive interference cancellation by means of spatial and termporal filtering
- Very low noise high dynamic range detection systems
- Near perfect theoretical Nyquist linear phase x/2 Hz filters

Information Transfer Capacity and Information Transfer Rate

- Advancements in coding algorithms will result in the ability to approach within 1 dB of the Shannon-Hartley limit Eb/No
- For a given unit bandwidth (in Hz) wireless systems will have information transfer rate parity with cable systems
  - BRI ISDN (near-term)
  - PRI ISDN (mid-term)
- In a faded mobile environment, information transfer rates of 1 MB/s at frequencies up to 2500 MHz are envisioned
- In fixed station point-to-point, and multi-point wireless links where more bandwidth (in Hz) are available, information transfer rates will increase into the GB/s range

Antenna Technology

- Broadband (100-2500 MHz) high efficiency, linear adaptive phase and amplitude multi-beam forming with dynamic tracking and acquisition and adaptive nulling interference cancellation initially in fixed station applications and eventually in mobile applications

System Architectural Features and Frequency Reuse

- Proliferation of highly scalable linear system architectures to support bandwidth and spectrally efficient technologies employing
  - Frequency Division Multiple Access (FDMA)
  - Time Division Multiple Access (TDMA)
  - Spread Spectrum Code Division Multiple Access (SS-CDMA)
- Linear architectures amenable to Urban, Suburban, and Rural Service Area Scalability, i.e., 1-100 km or more
- Private and public linear system architectures will support adaptive and dynamic information transfer rate on demand